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APPLICATION OF A HELICOPTER MATHEMATICAL MODEL TO THE LANGLEY DIFFERENTIAL MANEUVERING SIMULATOR FOR USE IN A HELICOPTER/FIGHTER EVASIVE MANEUVER STUDY

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16. Abstract

A real-time simulation study was conducted using the Langley Differential Maneuvering Simulator to determine and evaluate helicopter evasive maneuvers when attacked by fighter aircraft. A general helicopter mathematical model was modified to represent an H-53 helicopter. The helicopter model was compared to H-53 flight test data to determine any differences between the simulated and actual vehicles. The simulated helicopter was also subjectively validated by participating pilots. Two fighter mathematical models validated in previous studies were utilized for the attacking aircraft. References are provided for their description and documentation.

The results of this simulation study have been verified in a flight test program conducted by the U. S. Air Force and were found to closely match the flight results.

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SUMMARY

A real-time simulation study was conducted using the Langley Differential Maneuvering Simulator to determine and evaluate helicopter evasive maneuvers when attacked by fighter aircraft. A general helicopter mathematical model was modified to represent an H-53 helicopter. The helicopter model was compared to H-53 flight test data to determine any differences between the simulated and actual vehicles. The simulated helicopter was also subjectively validated by participating pilots. Two fighter mathematical models validated in previous studies were utilized for the attacking aircraft. References are provided for their description and documentation.

The results of this simulation study have been verified in a flight test program conducted by the U.S. Air Force and were found to closely match the flight results.

INTRODUCTION

During past military operations, air superiority by friendly forces has provided the rescue helicopter with relative freedom from attack by fighter aircraft. However, current technology makes it entirely possible that in future conflicts air superiority may not be maintained. In an effort to retain a viable combat capability in such a hostile environment, the U.S. Air Force defined a test program to evaluate and refine known helicopter evasive maneuvers and develop and verify additional maneuvers which will decrease the helicopter's vulnerability to attack.

Langley Research Center was asked to support the U.S. Air Force in one phase of this program. This consisted of utilizing the Langley Research Center Differential Maneuvering Simulator (DMS) to simulate one-on-one encounters between a rescue helicopter and various fighter aircraft. This report describes the mathematical model and hardware modifications utilized for this study. In addition, a summary of the simulated helicopter characteristics as compared to an H-53 helicopter are provided.

LIST OF SYMBOLS

X_A	lateral cyclic stick position, cm (in)
X_B	longitudinal cyclic stick position, cm (in)
X_C	collective stick position, cm (in)
X_P	pedal position, cm (in)
s	Laplace operator
α	angle of attack, deg
δ_A	lateral cyclic control position, deg
$\hat{\delta}_A$	error signal, deg
δ_{AS}	lateral cyclic SAS input, deg
δ_{AT}	lateral cyclic trim position, deg
δ_B	longitudinal cyclic control position, deg
$\hat{\delta}_B$	error signal, deg
δ_{BS}	longitudinal cyclic SAS input, deg
δ_{BT}	longitudinal cyclic trim position, deg
δ_{PS}	pedal SAS input, deg
θ	pitch angle, deg
θ_T	trim pitch angle, deg
$\hat{\theta}$	error signal, deg
ϕ	roll angle, deg
ϕ_T	trim roll angle, deg
$\hat{\phi}$	error signal, deg
ψ	heading angle, deg
ψ_{HH}	heading hold angle, deg
$\hat{\psi}$	error signal, deg

PROBLEM DESCRIPTION

The primary purpose of this study, documented in reference 1, was to evaluate existing helicopter/fighter aircraft evasive tactics and develop new tactics necessary to minimize the vulnerability of rescue helicopters to attack from fighter aircraft. The attacking fighter pilot's task was to track and destroy a helicopter performing low-altitude evasive maneuvers. The helicopter pilot's task was to successfully avoid repeated attacks by the fighter assuming a level terrain such as desert or water. The initial intercept was assumed to be accomplished and both pilots concentrated on the tactics required to perform their respective mission tasks. The helicopter pilot was to determine the optimum defensive maneuvers required to avoid the fighter aircraft, and the fighter pilot was to determine the optimum tactics required to continue the engagement to a successful completion.

In addition, the following specific objectives were evaluated:

(a) Capability of the fighter aircraft to attack a rescue helicopter.

(b) Capability of the helicopter crew to detect attacking fighter aircraft.

(c) Capability of the rescue helicopter to evade an identified attacking fighter aircraft using standard evasive tactics and techniques.

(d) Develop and refine evasive maneuvers for the helicopter.

(e) Determine helicopter characteristics vulnerable to attack by fighter aircraft.

(f) Determine additional aircrew training requirements.

In order to accomplish these objectives, a helicopter with flight characteristics similar to the H-53 helicopter was programmed for one DMS sphere, and a fighter aircraft was programmed for the other DMS sphere. Two separate fighter aircraft were utilized for the study. The results of the study are documented in reference 1. The remainder of this report deals with descriptions of the software and hardware involved and documentation of the flight characteristics of the simulated helicopter.

Hardware Description

The Langley Differential Maneuvering Simulator (DMS), Figures 1 and 2, provides a means of simulating two piloted aircraft or spacecraft operating in a differential mode with a realistic cockpit environment and a wide angle external visual scene for each of the two pilots. The system consists of two identical fixed-base cockpits and projection systems, each based in a 12.2m (40 ft.) diameter projection sphere. Each projection system consists of a sky-earth projector to provide a horizon reference and a system for target-image generation and projection. The external sky-earth scene provides reference in all three rotational degrees of freedom in a manner which allows unrestricted aircraft motions. The sky-earth scene has no translation motion. The external visual scene also provides continuous rotational and bounded, 91.4m - 13716m (300 ft. - 45,000 ft.), translational reference to a second (target) vehicle in six degrees-of-freedom. The target image presented to each pilot represents the aircraft being flown by the other pilot in this dual simulator. Each cockpit provides essential instruments and displays along with a wide angle Heads-Up-Display. Kinesthetic cues in the form of a G-suit pressurization system, cockpit buffet, and programmable control forces are provided to each pilot consistent with the aircraft's motions.

Several modifications were made to one of the cockpits to allow for a nearer representation of a helicopter cockpit and to provide translational cues. The standard fighter cockpit canopy of the DMS was masked off to provide essentially the same field-of-view above and to the sides as that of an H-53 helicopter. No modifications were made to provide a lower field-of-view forward and to the side since no hovering or nap-of-the-earth cases could be simulated. A light was used in the cockpit to flash at a predetermined altitude to provide a vertical translation cue since no terrain growth could be simulated by the hardware. The terrain visual representation is fixed at an altitude of 3048m (10,000 ft.).

Since the DMS contains fighter cockpits, no collective stick was available, therefore the fighter throttle was utilized with the throttle

moving forward for down collective motion and backward for up motion. The pilots had no trouble adjusting to this. Finally the cockpit buffet system was utilized to simulate the low speed and high speed regions where high vibration occurs due to rotor loading for the helicopter.

In the fighter sphere the pilot was presented with engine and gun fire noise. No model of a helicopter was available for use in the visual presentation, therefore, an available fighter model was utilized. The fighter pilots had no trouble adjusting to the fighter image since the image moved slowly and held attitudes which would be typical of a helicopter.

The helicopter crew members were represented by two crewmen, one located on each side of the cockpit, to act as spotters in aiding the pilot in keeping track of the fighter's position as they would in actual flight.

Fighter Aircraft Mathematical Model

Two fighter aircraft mathematical models were utilized for this study. Aircraft A was a modern twin-engine fixed-wing fighter aircraft having leading edge slats. The equations and data used to represent this vehicle are presented in reference 3. Aircraft B was a modern delta-wing fighter aircraft having an aft horizontal tail. The equations and data used to represent this vehicle are presented in reference 4. Both of these fighter aircraft models have been used in previous simulation studies and are considered valid models for the vehicles.

Helicopter Mathematical Model

A mathematical model and digital real-time simulation program for a single-rotor helicopter (reference 5) developed at Langley Research Center formed the basis for the helicopter portion of this study. The helicopter mathematical model is a total force and moment model and is designed to represent the entire operational flight envelope including hover, autorotation, transition, and forward flight. The equations include dynamic modeling of the main rotor (modified blade element theory) and airframe. These general equations are presented in Appendix A of reference 5. The computer program is written in a modular form, figure 3, thus allowing entire sections of the vehicle to be replaced with relative ease, for example, a

new empennage model could replace the present model without requiring changes to the rest of the computer program.

Since a detailed mathematical model was not available to represent an H-53 rescue helicopter, an existing AH-1G helicopter representation, described in reference 5, was modified to give the characteristics of an H-53 helicopter. In order to approximate the performance of an H-53 helicopter, three major modifications were made to the existing program. These consisted of increasing the rotor lift by 10%, decreasing the total vehicle drag by 40%, decreasing the programmed weight from 4002kgs (8823 lbs.) to 2948kgs (6500 lbs.), and by biasing the collective stick position by -7.62cm (-3 in.) when calculating the blade pitch due to collective input.

To approximate the handling qualities of an H-53 helicopter, a stability augmentation system was added to the computer program. The equations for this system are as follows:

$$\delta_{AS} = -.6(.7s + 1)\hat{\phi} + \frac{3.76}{.8s + 1}\hat{\delta}_A$$

$$\delta_{BS} = .55(.88s + 1)\hat{\theta} + .8\hat{\delta}_B$$

$$\delta_{PS} = (.726s + .441)\hat{\psi}$$

where

$$\hat{\phi} = \phi - \phi_T$$

$$\hat{\theta} = \theta - \theta_T$$

$$\hat{\psi} = \psi - \psi_{HH}$$

$$\hat{\delta}_A = \delta_A - \delta_{AT}$$

$$\hat{\delta}_B = \delta_B - \delta_{BT}$$

Documentation of Helicopter Model Characteristics

Three types of objective tests were conducted for comparison with flight test data (reference 6) of an H-53 helicopter. These were performance tests consisting of autorotation and climb, static trim stability tests, and dynamic

response tests to a step input. The autorotation performance (Table I) and the the climb performance (Table II) tests were conducted by the participating U.S. Air Force helicopter pilots. Table I shows that a significant difference existed between the simulation data for autorotation and that of the actual vehicle. Table II shows that the climb performance comparison between simulation and flight test was reasonable expecially at cruise speeds. Since autorotation and climb performance are not independent of each other in the mathematical equations, and an increase in one through equation and/or data adjustment, results in a decrease in the other, the decision was made to model climb performance as well as possible, thus sacrificing the autorotation performance. Maximum rate of descent in the simulator was found to be in excess of 1829m/min (6000 ft./min.) at 170 knots.

Table III presents static trim stability data for the simulation. It can be seen from the longitudinal cyclic stick position (X_B) and pitch attitude (θ) data that the helicopter is statically stable, and in the opinion of the participating pilots, it exhibited similar longitudinal characteristics to an H-53 helicopter.

Table IV presents a comparison of dynamic response characteristics for the simulation versus flight tests. The tests consisted of a 2.54cm (1 in.) step input on each of the various controls.

The data shows favorable comparisons for attitude displacement and maximum angular velocity. Some difference is seen in maximum angular acceleration for all controls with the maximum difference being for right and left pedal inputs.

As a final validation of the simulation, each of the participating pilots subjectively evaluated the helicopter during a set of flights and agreed that the simulation was adequate for the study to be conducted. A series of follow-on flights in an H-53 helicopter by each of the pilots substantiated their opinions that the simulation was comparable to an H-53 helicopter with the actual vehicle being more responsive and easier to maneuver.

CONCLUSIONS

A real-time man-in-the-loop simulation study using the Langley Differential Maneuvering Simulator was conducted to determine and evaluate helicopter evasive maneuvers when being attacked by fighter aircraft. A real-time simulation of a general helicopter was modified to obtain characteristics typical of an H-53 helicopter. The helicopter was subjectively evaluated by the pilots, and objectively compared to H-53 helicopter flight test data, and was determined to adequately represent the desired vehicle. The tactical results of this study are documented in reference 1. The U.S. Air Force has since conducted an extensive flight evaluation of the tactics developed in the DMS and found that the simulation results agreed completely with those determined during the flight evaluation, reference 7. In addition, all study participants feel that the simulation studies saved numerous aircraft flight hours during the flight evaluation and also significantly increased the margin of safety while performing these high risk maneuvers in flight.

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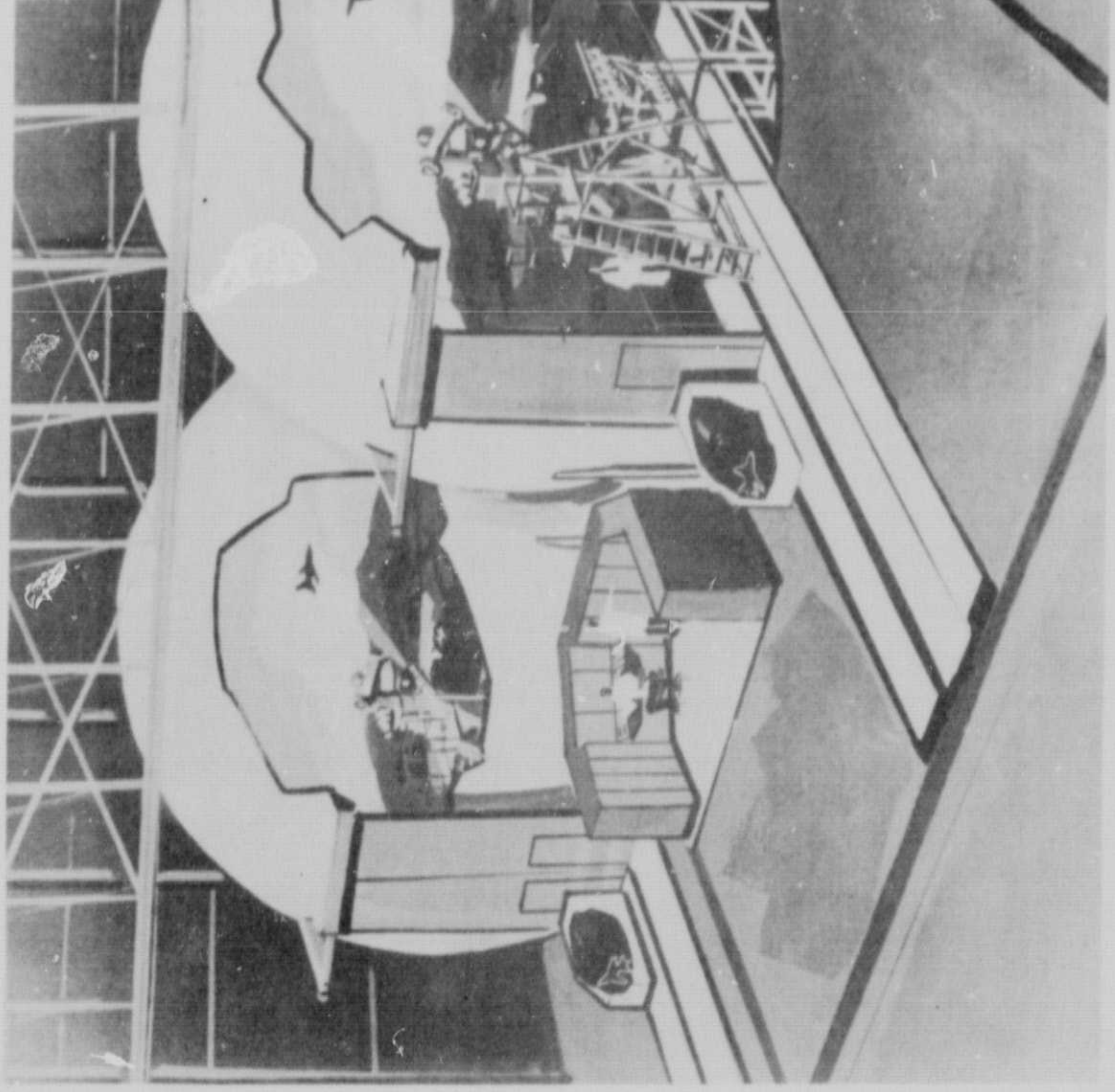

Figure 1.- DMS Facility

Figure 2.- DMS Pilot's View

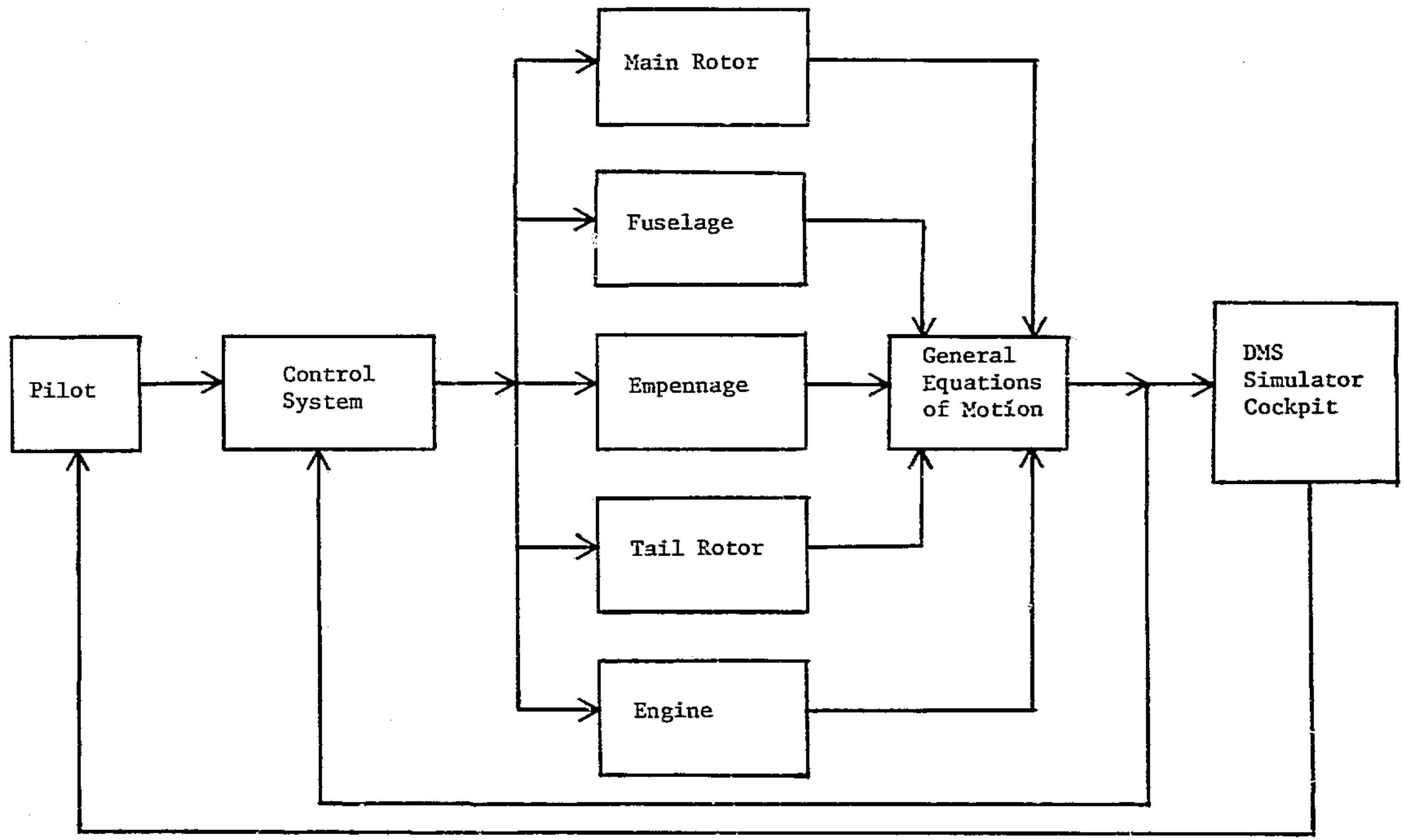

Figure 3.- HELICOPTER MATHEMATICAL MODEL BLOCK DIAGRAM

TABLE I. AUTOROTATION PERFORMANCE

AIRSPEED, KTS	SIMULATION m/min	(ft/min)	FLIGHT TESTS m/min	(ft/min)
50	518	(1700)	1006	(3300)
71	381	(1250)	602	(1975)
91	305	(1000)	640	(2100)
110	335	(1100)	762	(2500)
130	366	(1200)	945	(3100)

CONDITIONS: 1372m (4500 ft PA), MID CG, AUTOROTATION

TABLE II. CLIMB PERFORMANCE

AIRSPEED, KTS	SIMULATION m/min	(ft/min)	FLIGHT TESTS m/min	(ft/min)
51	975	(3200)	625	(2050)
70	914	(3000)	747	(2450)
89	823	(2700)	823	(2700)
108	671	(2200)	732	(2400)
130	518	(1700)	427	(1400)

CONDITIONS: 1372m (4500 ft PA), MID CG, MAX POWER

TABLE III. SIMULATION STATIC TRIM STABILITY

AIRSPEED, KTS	X_C, cm	(in)	X_B, cm	(in)	X_A, cm	(in)	X_P, cm	(in)	θ, deg	ϕ, deg	α, deg
0	11.94	(4.70)	-3.81	(-1.50)	.25	(.10)	1.02	(.40)	-1.5	-1.00	—
10	10.92	(4.30)	-3.56	(-1.40)	.25	(.10)	1.27	(.50)	-1.5	-.90	—
20	8.86	(3.49)	-3.58	(-1.41)	.56	(.22)	1.93	(.76)	-1.6	-.75	-14.0
30	6.91	(2.72)	-3.45	(-1.36)	.89	(.35)	2.59	(1.02)	-1.8	-.60	-7.0
40	5.46	(2.15)	-3.38	(-1.33)	1.14	(.45)	3.05	(1.20)	-1.9	-.55	-2.0
50	4.45	(1.75)	-3.33	(-1.31)	1.35	(.53)	3.38	(1.33)	-2.1	-.50	-4.0
60	3.81	(1.50)	-3.28	(-1.29)	1.50	(.59)	3.61	(1.42)	-2.3	-.45	-3.5
70	3.23	(1.27)	-3.25	(-1.28)	1.63	(.64)	3.81	(1.50)	-2.5	-.45	-3.5
80	2.87	(1.13)	-3.23	(-1.27)	1.75	(.69)	3.99	(1.57)	-2.8	-.50	-3.5
89	2.84	(1.12)	-3.02	(-1.19)	1.73	(.68)	4.06	(1.60)	-3.1	-.55	-3.5
98	3.07	(1.21)	-2.72	(-1.07)	1.65	(.65)	4.11	(1.62)	-3.4	-.70	-3.7
107	3.58	(1.41)	-2.31	(-.91)	1.52	(.60)	4.14	(1.63)	-3.8	-.90	-4.0
116	4.50	(1.77)	-1.88	(-.74)	1.40	(.55)	4.17	(1.64)	-4.2	-1.00	-4.5
125	5.56	(2.19)	-1.30	(-.51)	1.19	(.47)	4.14	(1.63)	-4.5	-1.25	-4.7
140	10.67	(4.20)	.51	(.20)	.51	(.20)	3.56	(1.40)	-5.0	-1.00	-4.0
150	15.24	(6.00)	1.27	(.50)	.51	(.20)	2.29	(.90)	-4.0	-1.00	-4.0
160	19.30	(7.60)	2.29	(.90)	0.	(0)	1.78	(.70)	-6.0	-2.00	-4.0
170	23.62	(9.30)	3.30	(1.30)	0.	(0)	1.02	(.40)	-7.0	-3.00	-6.0

CONDITIONS: 304.8m (1000 ft PA), SAS ON

TABLE IV. DYNAMIC RESPONSE COMPARISON

INPUT	SOURCE	ATTITUDE DISPLACEMENT, deg	TIME LAPSE, sec	MAXIMUM ANGULAR VELOCITY, deg/sec	TIME LAPSE, sec	MAXIMUM ANGULAR ACCELERATION, deg/sec^2	TIME LAPSE, sec
PITCH UP	Flight Test	8	2.5	4	.75	12	.50
	Simulation	8	2.5	6	.75	20	.20
PITCH DOWN	Flight Test	-7	2.5	-4	.75	-12	.50
	Simulation	-11	2.5	-6	.75	-15	.20
ROLL RIGHT	Flight Test	6	1.5	6	.75	22	.30
	Simulation	5	1.5	6	.60	26	.30
ROLL LEFT	Flight Test	-8	1.5	-5	.70	-18	.25
	Simulation	-8	1.5	-7	.50	-27	.20
YAW RIGHT	Flight Test	7	2.5	4	1.50	14	.25
	Simulation	4	2.5	5	.25	50	.20
YAW LEFT	Flight Test	-2	1.5	-2	.75	-7	.25
	Simulation	-3	1.5	-5	.25	-55	.20

CONDITIONS: 113 KTS, 2134m (7000 ft PA), SAS ON; 2.54cm (1 in) STEP INPUTS